Production, consumption and research on solar energy

The Spanish and German case

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Renewable energy research 1995-2009 – a case study of wind power research in EU, Spain, Germany and Denmark

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Abstract:

The paper reports the developments and citation patterns over three time periods of research on Renewable Energy generation and Wind Power 1995-2011 in EU, Spain, Germany and Denmark. Analyses are based Web of Science and incorporate journal articles as well as conference proceeding papers. Sxcientometric indicators include publication collaboration ratios, top-player distribution as well as citedness and correspondence analyses of citing publications, relative citation impact, distributions of top-cited as well as top-citing institutions and publication sources and cluster analysis of citing title terms to map knowledge export areas.

Findings show an increase in citation impact for Renewable Energy and Wind Power research albeit hampered by scarcely cited conference papers. Although EU maintains its global top position in producing Renewable Energy and Wind Power research the developments of EU and German world shares as well as citation impact are negative during the most recent seven year period. During the same time the citation impact of Spain and Denmark increase and place both nations among the top-ranking countries in Wind Power research. Spain is the only EU country that increases its world production share from 2000. China is currently ranked three after EU and USA in research output, however with a very low citation impact. Spain, Denmark and Germany each demonstrates distinct collaboration patterns and publication source and citation distribution profiles. More than half the citations to EU Wind Power research are EU-self citations. An expected intensified EU collaboration in the Wind Energy field does not come about. The most productive research institutions in Denmark and Spain are also the most cited ones.

Introduction

New economical patterns in most of the developed countries are closely linked to the incorporation of sustainability criteria in the production sectors based on scientific and technological knowledge. A fundamental strategy in the fields of environmental sustainability consists in fostering the generation of new knowledge as well as adapting the existing one, originally intended for other purposes. A clean production, an efficient use of energy and the appropriate recycling of natural resources are some of the areas that are dependent of this new knowledge.

The European Union is often regarded a front runner with respect to strategies and goals for global decrease of carbon dioxide and increase of alternative energy production, research and development (European Commission, 2008; Giljum et al., 2008; Nash, 2009). As EU partner the Spanish government developed a Renewable Energy Plan 2005-2010, with the goal that 12.1% of primary energy consumption in 2010 should come from renewable energy. The proposed investment for 2005-2010 was 23,598 million Euros, of which 2.9% was funded by the Spanish government, which represents 681millones Euros. (IDEA, 2005). Further, Spain has initiated plans for the national developments of eco-economy and R&D and innovation in the fieldsof Renewable Energy (Ministerio de Medio Ambiente Rural y Marino, 2009; Trieb, 2007). In order to establish a national workable strategy and policies for this development detailed information is required by the government on patterns and trends of the scientific and technical knowledge production as a result of R&D activities in public and private sectors in these areas in Spain as well as globally.

In this respect the SAPIENS Project (Scientometric Analyses of the Productivity and Impact of Eco-economy of Spain) has as main goal the analysis of scientific and technological capacities of Eco-economy in Spain 1995-2009, cited 1995-2011, seen in a global context through quantitative and qualitative R&D indicators. The project is supported 2011-13 by the National Research Plan of the Ministry of Science and Innovation and will be conducted between the Spanish Reseach Council (CSIC) and the Carlos III University, Laboratory of Information Metric Studies (LEMI), which acts as the the coordinating institution of the project. The Royal School of Library and Information Science, Copenhagen, Denmark, acts as academic partner.

SAPIENS has three objectives. First, to analyse the patterns and trends concerning the creation of knowledge on sustainable energy and associated research fields through scientific publications and patents; secondly, to observe to what extent Spain compared to two other European countries, Germany and Denmark, contribute to this development; third, to trace the impact and use of the new knowledge worldwide. In this respect the project is in line with the proposal for an EU science policy indicator framework for sustainable energy (Streimikiene and Šivickas, 2008).

Earlier related work on R&D patterns in sustainable or renewable energy and associated fields, based on publication, citation and impact analyses focused on science and technology tracking (Kajikawa et al., 2007; 2008), national trends in the development of the area of research on climate change (Schneider and Larsen, 2009) or the design of alternative indicators (Siche, 2010). With respect to review and research overview articles on renewable energy research and policy in a European context one may among others refer to Johansson and Turkenburg (2004), Johnstone, Hašcic and Popp (2010) and Kaldellis and Zafirakis (2011).

The following blocks of research areas of sustainable energy and associated fields were analyzed as part of the SAPIENS Project:

Block A: *Renewable Energy Generation*, sub-fields: Renewable Energy; Wind Power; Solar Energy; Geothermal Energy; Wave (Marine/Ocean) Energy;

Block B: *Utilization and Re-utilization of Resources*, subfields: Energy Efficiency; Combined Energy Systems; Soil; Air; Waste;

Block C: *Biological Sub-products*, subfields: Bio Fuels; Biomass Energy & Biogaz; Sustainable Development.

Within the framework of the three objectives of Project SAPIENS the present paper analyzes the research publications and citations produced in the Renewable Energy Generation sub-field *Wind Power* associated with EU, Spain, Germany and Denmark in a global context, 1995-2011[1].

According to Global Wind Energy Statistics 2006 (GWEC, 2007) Europe was the market leader in wind energy capacity development. According to the report (GWEC, 2007, p. 4) in 2006 "[the] countries with the highest total installed capacity are Germany (20,622 MW), Spain (11,615 MW), the USA (11,603 MW), India (6,270 MW) and Denmark (3,136 MW)." Thus, the three selected countries were the most productive EU countries in relation to wind energy capacity installed. This is still the case five years later. According to the European Wind Energy Association (EWEA, 2012a, p. 2) Germany (29,060 MW) and Spain (21,674 MW) are the front runners on the wind energy capacity market in EU with Denmark (3,871 MW) ranked as number seven in absolute numbers. Thus, in terms of capacity per capita Denmark is among the most wind energy productive EU (and world) countries. Historically, the three countries are regarded the central pioneers in wind energy development: "[in] 2000 the annual wind power installations of the three pioneering countries – Denmark, Germany and Spain – represented 85% of all EU wind capacity additions. In 2011, this share has decreased to 34%. Wind power is increasingly being installed across Europe" EWEA, 2012a, p. 9).

There are certainly economic spin-offs from the wind power industrial activities. As stated by (EWEA, 2012b, p. 35): "[European] players mainly export added value equipment and services: wind turbines, technology, engineering services, controlling software and hardware, electrical equipment, rotors, transformers and financial services. The growth and consolidation of the wind energy industry in Europe over the last twenty years has had a major impact on employment. This industry has created jobs, not only in turbine manufacturing and electricity production (direct employment) but also in many different economic sectors and activities (indirect employment). Until recently, wind industry job creation was mainly in the three most developed wind energy markets: Germany, Denmark and Spain. However, as a result of the expansion

[1] Analyses of patents and other indicators of technical innovation and developments are published in later publications.

of wind energy to other large economies and new emerging markets, along with offshore increasing (offshore wind energy is between 2.5 and three times more labor intensive than onshore wind energy), job creation is likely to accelerate throughout the EU." It is therefore relevant to concentrate the ensuing comparative analyses on those three countries - but seen in context of the development of wind energy in rest of EU and the world and in context of renewable energy as such.

In 2011 Wind Power energy accounted for 30 % of the *new* renewable energy capacity in EU with new Solar Energy power installations constituting the largest share (66 %). In the current total EU power capacity mixture the Wind Power share is 10 % and Solar Energy 5 % (EWEA, 2012, p. 6-8). In the future all three countries are more heavily depending on sustainable energy resources when national nuclear power plants are phased out (Germany and Spain) or own natural gaz resources are exhausted (Denmark). Analyses of the R&D developments of sustainable energy are consequently very important for policy making at European community as well as national levels.

One assumption behind the present analyses is that owing to the strategic energy planning and public rhetoric on the matter the EU countries has increased their world share in Wind Power research during the last decade. Secondly, owing to the EU research frameworks one might hypothesize that national and institutional collaboration increases and cooperation profiles and citation patterns become increasingly similar over time across the three selected countries.

The following research questions form part of the present study:

1. Which central trends are visible with respect to the global Renewable Energy Generation, and Wind Power research production in particular, 1995-2009(11)? Focus is on top players in the general research area and the Wind Power sub-field, productivity and citation impact;
2. Which countries and research institutions constitute the collaboration profiles of Spain, Germany and Denmark in Wind Power research 1995-2009? Focus is on the collaboration ratios and patterns of knowledge production;
3. Which countries, research institutions, publication sources and subject areas constitute the network of knowledge export in Wind Power research from Spain, Germany and Denmark 2005-2009(11)? – and how do such distributions overlap with the knowledge production profiles? Focus is on citation patterns as indicators of knowledge export.

The analyses were based on a subset of Web of Science data (WoS, Thomson Reuters) retrieved, downloaded, extracted and cleaned up during January-February 2012, covering three five-year periods, each with a seven-year citation window: 1995-1999 (cited 1995-2001), 2000-2004 (cited 2000-2006) and 2005-2009 (cited 2005-2011). In addition, in a few cases the publications published 2010-11 were included to observe the up-to-date global trends for the Renewable Energy Generation block as such and Wind Power research in particular.

The article is structured as follows. Initially, the entire Renewable Energy Generation research block is analyzed 1995-2011 for publication and citation developments, dominant players as well as citation impact development. The analyses serve as context for the following sections that narrow down the analyses to cover the research development of the sub-field Wind Power. The sub-field itself is analysed with respect to international collaboration, world shares of production, citedness by country, region and by document types 1995-2011. Then the citation impact and distribution across citing countries to the field and to the EU research in the field 2005-09, cited 2005-11, are analysed. Next follows analyses of Wind Power research in Spain, Denmark and Germany 1995-2009. International collaboration per country is compared to the intra-EU collaboration ratio, and number of countries, institutions and authors per document, citedness as well as top-productive institutions and sources are analysed and discussed per country. This is followed by an analysis of sources and topics publishing Wind Power research in the three countries and a citation analysis consisting of impact developments 1995-2011. Correspondence analyses and plots of countries citing the three countries are included across two periods: 2000-2006 and 2005-2011 followed by analyses of the knowledge export patterns and distribution across countries, institutions and sources citing Spain, Denmark and Germany. This includes Spearman´s rank correlation analyses of distributions of producing and citing countries and sources. The articles ends with a discussion and concluding remarks.

Methodology

Initially the retrieval profile for each block and sub-field was elaborated, searched, adjusted iteratively online in WoS, and finalized after control for and exclusions of unwelcome topical facets that might bias the analysis outcome. For instance, in the Wind Power retrieval profile care was taken to exclude ´solar wind power/energy´ aspects from the final subset. Appendix A presents the retrieval profile for Renewable Energy Generation, including the sub-field profile for Wind Power.

First the overall results were retrieved online through WoS for the Renewable Energy Generation block, in order to establish a broader global context on citation impact to the Wind Power research analysis. In case of sub-field sets too large for WoS to handle when generating online citation reports, i.e. sets above 10,000 items, the set was logically divided into subsets for which the analyses were aggregated later. The sub-field on Solar Energy constitutes such a large set. Secondly, using the final retrieval profile on Wind Energy, Appendix A, 1520 source records and 6612 citing records covering the three countries were downloaded from the WoS databases (Thomson Reuters) Science Citation Index, Social Science Citation Index as well as the corresponding conference proceedings indexes. They constitute 34 MB of Wind Power research data 1995-2009(11), including abstracts and references, out of 5.59 GB downloaded WoS records defined by the three blocks of the SAPIENS research areas.

The cited and citing datasets were restricted to journal and review articles as well as conference papers and excluding document types like book reviews, news items and editorial materials. Both datasets were reloaded into a local SQL database configuration in order to be able to extract a variety of data over the aforementioned three periods of time to form a range of analyses and indicators. In a few cases the publication analysis of cited records was extended to include the most recent period 2010-11. Along this process both datasets were cleaned up with respect to institutional name forms from the three countries. Although the country names and source titles were already controlled in WoS a second round of checking took place during processing. The following indicators and analyses became generated by means of the two datasets as well as the online WoS search on the entire Renewable Energy research area, divided into the three analysis periods and citation windows:

- Trends of global field impact, major national players and EU cooperation in Renewable Energy Generation, 1995-2009, plus extension into 2010-11 (cited 1995-2011);
- Trends of field impact, citedness and major national players in Wind Power research globally, 1995-2009, plus extension into 2010-11 (cited 1995-2011);
- Trends of collaboration ratios at national level in Wind Power research and of journal patterns for 2005-2009;
- International, institutional and journal trends as well as source citation patterns for Spain, Germany and Denmark in Wind Power research through correspondence analysis and citedness ratios 1995-2009 (cited 1995-2011) as well as correlation coefficient analyses;
- Trends of topical productivity and citation networks (knowledge export) of Wind Power research in Spain, Germany and Denmark by means of keyword distribution and cluster analysis 2005-2009 (cited 1995-2011).

Regional productivity analyses were done by isolating duplicate records from intra-regional collaboration. National collaboration ratios were calculated as the number of records with more than one affiliation or country over the total number of records, determined by a period. Citedness ratios were calculated as the number of records cited at least once over the total number of records, determined by a period, and including country self-citations. Correspondence analysis was performed according to the R package version 0.33 (Greenacre, 2010).The Spearman´s rank correlation coefficient ρ is applied for correlation analyses. In the cluster analyses the Ward method (1963) is used.

Findings on Renewable Energy research 1995-2009(-11)

Table 1 demonstrates the development of the entire block of Renewable Energy research world-wide across the three periods and divided into the appropriate sub-fields.

Table 1. Global publication, citation and impact trends 1995-2009, cited 1995-2011, Renewable Energy Generation research (WoS, 2012).

	Renew. Energy			Wind Power			Solar Energy			Geo-thermal			Wave Energy			*Total:*		
	Publ.	Cits.	c/p	Publ.	Cits.	c/p	Publ.	Cits.	c/p	Publ.	Cits.	c/p	Publ.	Cits.	c/p	Publ.	Cits.	c/p
1995-99 (-01)	1583	2296	1.5	1107	1518	1.4	8622	38310	4.4	1743	7028	4.0	770	3222	4.2	13825	52374	3.8
2000-04 (-06)	2197	6947	3.2	1650	4571	2.8	12619	92578	7.3	1875	10535	5.6	895	3673	4.1	19236	118304	6.2
2005-09 (-11)	7104	52145	7.3	7018	30693	4.4	26585	369890	13.9	2615	18281	7.0	1444	6859	4.8	44766	477868	10.7
1995-2009 (-11)	10884	61388	5.6	9775	36782	3.8	47826	500778	10.5	6233	35844	5.8	3109	13754	4.4	77827	648546	8.3

The research production in the sub-fields Renewable Energy, Wind Power and Solar Energy almost quadruples from 1995-99 to 2005-09. However, the growth in Geo-thermal Energy and Wave energy research is much more modest (50 % and 87 %). One should consider that WoS during the analysis period included conference proceedings as part of the database system. Hence the vast increase for all fields after 2004.

For all sub-fields except for Wave Energy the citation impact also increases rapidly over the 15 year period with an average factor of 3. In particular Solar Energy research demonstrates a quite high impact (13.9, cited 2005-11) compared to the other four sub-fields, with Wind Power and Wave Energy research displaying alike lower impact scores around 4.5. In Wind Power research as well as for the total Renewable Energy block citation impact almost triples over the period. A reason may be the widespread penetration of trendy Renewable Energy fields into related academic research fields caused by their social and political recognition during the last decade. Only the Geo-thermal and Wave (Ocean) Energy research sub-fields demonstrate a slow or no growth in impact. Both sub-fields are smaller research specialities, so far with less prestige and scientific as well as public penetration. In the case of Wind Power research the ensuing sections demonstrate in detail from which sources the citations derive with respect to document types, countries and citing fields.

Table 1 includes documents covering more than one sub-field. According to Appendix A the total research area contains 41,797 documents (2005-2009) with the overlaps logically removed during the online searching in WoS. The overlap for that period is 44,766 items (Table 1) minus 41,797 = 2,969 items or 7 %. For the two earlier periods the overlaps are 4 % respectively. Thus, recently the overlap has increased between the sub-fields. It is probable that we observe a progression of interaction effects among the energy research fields.

Table 2 demonstrates the distribution of the three document types over the five sub-fields, 2005-2009. Evidently conference papers play a significant role in all but the Geo-thermal sub-field. As a highly technical engineering field Wind Power demonstrates the highest proportion of conference papers (60 %). Their volume provides a substantial effect on the present analysis results as well as on WoS itself as a data source.

Note that in addition to the aforementioned overlap between sub-fields, a portion of documents is indexed both as conference paper and article. They are (probably) published in thematic serial issues. Hence the larger sums displayed in Table 2 compared to Table 1 for each sub-field.

Table 2. Document type distribution 2005-09 across the sub-fields of Renewable Energy (WoS, 2012)

	Renew. Energy		**Wind Power**		**Solar Energy**		**Geo-thermal**		**Wave energy**		**Total:**	
	Publ.	%	Publ.	%	Publ.	%	Publ.	%	Publ.	%	Publ.	%
Journal article	3759	49.4	2750	37.5	19763	66.6	2059	73.1	1043	62.6	29374	59.9
Conf. Paper	3305	43.5	4384	59.9	8989	30.3	601	21.3	597	35.8	17876	36.4
Review article	532	7.0	189	2.6	890	3.0	155	5.5	25	1.5	1791	3.6
Other	9	0.1	1	0.0	23	0.1	3	0.1	2	0.1	38	0.1
Total:	7605	100	7324	100	29665	100	2818	100	1667	100	49079	100
Online set	7105		7018		26585		2616		1554		44878	

Table 3 displays the top-20 player distribution in the total research block consisting of 77,827 documents across the three periods, plus 29,635 items covering 2010-11, in total 103,193 publications. The recent two-year period is included to show the up-to-date trend with respect to publication world shares, Figure 1.

Table 3. Top-20 countries producing research on Renewable Energy Generation 1995-2011 (WoS, 2012).

1995-1999			**2000-2004**			**2005-2009**			**2010-2011**		
Country	**Publ.**	**%**	**Country**	**Publ.**	**%**	**Country**	**Publ.**	**%**	**Country**	**Publ.**	**%**
USA	3819	28.6	USA	4367	23.7	USA	8668	20.7	USA	6387	21.6
GERMANY	***1197***	***9.0***	JAPAN	2092	11.4	PEOPLES R CHINA	5043	12.1	PEOPLES R CHINA	4780	16.1
JAPAN	1131	8.5	***GERMANY***	***2025***	***11.0***	***GERMANY***	***3458***	***8.3***	***GERMANY***	***2304***	***7.8***
ENGLAND	913	6.8	ENGLAND	981	5.3	JAPAN	3405	8.1	SOUTH KOREA	1951	6.6
INDIA	606	4.5	PEOPLES R CHINA	904	4.9	ENGLAND	1898	4.5	JAPAN	1863	6.3
FRANCE	581	4.4	FRANCE	742	4.0	***SPAIN***	***1654***	***4.0***	TAIWAN	1367	4.6
AUSTRALIA	490	3.7	AUSTRALIA	671	3.6	INDIA	1613	3.9	ENGLAND	1281	4.3
CANADA	457	3.4	INDIA	652	3.5	FRANCE	1574	3.8	***SPAIN***	***1201***	***4.1***
ITALY	448	3.4	***SPAIN***	***618***	***3.4***	SOUTH KOREA	1477	3.5	INDIA	1111	3.7
RUSSIA	337	2.5	ITALY	608	3.3	CANADA	1404	3.4	FRANCE	1019	3.4
SWITZERLAND	290	2.2	NETHERLANDS	599	3.3	ITALY	1363	3.3	CANADA	1016	3.4
SPAIN	***289***	***2.2***	CANADA	553	3.0	AUSTRALIA	1119	2.7	ITALY	940	3.2
NETHERLANDS	251	2.9	SWITZERLAND	423	2.3	NETHERLANDS	1067	2.6	AUSTRALIA	791	2.7
PEOPLES R CHINA	250	2.9	RUSSIA	419	2.3	TAIWAN	1019	2.4	TURKEY	618	2.1
ISRAEL	205	2.5	SWEDEN	373	2.0	TURKEY	938	2.2	SWITZERLAND	525	1.8
MEXICO	192	2.4	TURKEY	312	1.7	SWITZERLAND	838	2.0	NETHERLANDS	523	1.8
GREECE	191	2.4	GREECE	308	1.7	SWEDEN	697	1.7	SINGAPORE	483	1.6
SWEDEN	177	2.3	SOUTH KOREA	307	1.7	GREECE	646	1.5	SWEDEN	404	1.6
NEW ZEALAND	173	2.3	MEXICO	295	1.6	***DENMARK***	***631***	***1.5***	***DENMARK***	***387***	***1.3***
TURKEY	144	1.1	BRAZIL	255	1.4	BRAZIL	577	1.4	GREECE	339	1.1
DENMARK	***131***	***1.0***	BELGIUM	237	1.3	RUSSIA	532	1.3	BELGIUM	319	1.1
118 countries			120 countries			138 countries			148 countries		
Total documents	13336		Total documents:	18425		Total documents:	41797		Total documents:	29635	

World productivity is in general increasing. Clearly, the US contribution is diminishing over the 17 year period with a slight increase 2010-11, while the Chinese and other Asian R&D growths are vast. The EU world share loses ground 2005-11. With respect to Germany, Spain and Denmark one observes Table 3 a constant advance in annual volume and world shares but not in ranking for Spain and a decrease in world share for Denmark in the latter period of time. Similarly, Germany continuously loses its world share but remain the leading EU country by far.

Figure 1 demonstrates that the 'old' dominant Western economies: USA, EU, Canada, Australia and New Zealand reduce their world segments during the analysis period. Simultaneously, the share of the countries outside the diagram diminishes, from 21.7 % in 2000-2004 to 12.7 % in 2010-11. India stays rather constant just below 4 %. Only *China* raises its world share (or their international penetration as measured by WoS) very rapidly, to become the second top-player at global level in Renewable Energy research. If Chinese publications in Chinese were included China would probably top the list of research players. Japan, South Korea and Taiwan supersede China in volume and also increase their segment, but not as steeply as China, mainly due to a reduced Japanese growth. In contrast to China and their own research in the area, the latter three countries do not display a high amount of wind energy capacity (GWEC, 2012).

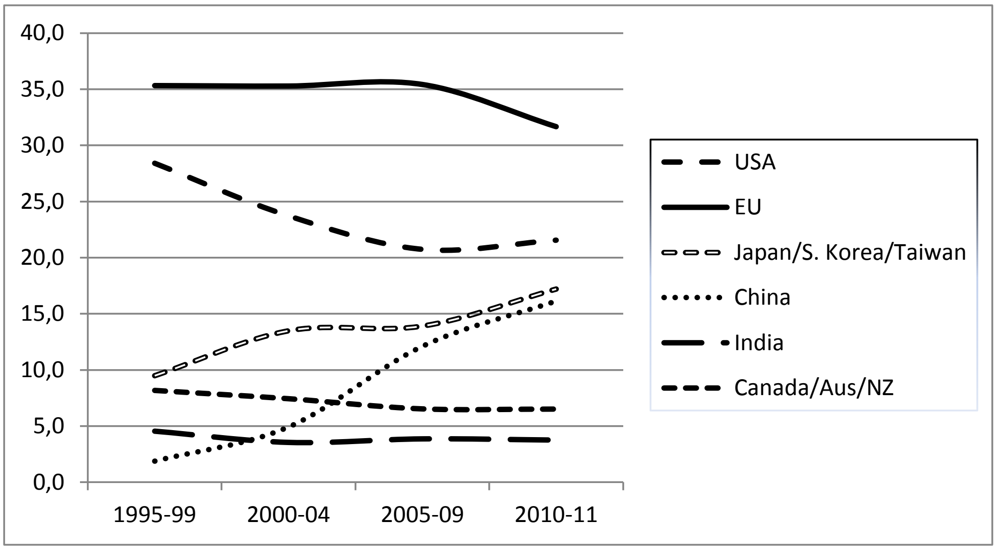


Figure 1. World shares in % of Renewable Energy research publications 1995-2011 (WoS, 2012).

These overall findings do *not support* the earlier made assumption of increased world share of EU in Renewable Energy research even though its global leadership continues. Similarly, in contrast to our assumption the *collaboration ratio* between EU countries is *diminishing*: from .10 (1995-99) over .25 (2000-04) down to .20 (2005-09) and .17 (2010-11). The findings do raise a serious warning of further decline of EU world share in the future research output. Indeed, some incongruity exists between the actual public EU stand on the climate and sustainable energy issues and the most recent research efforts put forward by EU countries in the latter area.

Wind Power Research production and citations 1995-2009(-11)

The development of Wind Power research and citations is depicted in Table 1. Citation impact triples 1995-2009 cited 1995-2011 to *4.4* during the last period. Table 2 shows the document type distribution 2005-09. 60 % of the publications during this period are conference papers. How does that fact contribute to the increased citation impact?

Table 4 demonstrates that the conference papers do *not* contribute positively to the impact; on the contrary. The largest portion of citing documents derives from journal articles that provide citations mainly to journal articles. Proceeding papers supply very much less citations and then mostly to the journal articles, less to the proceedings papers themselves. The distribution is thus very *asymmetric*. The increase in impact,

Table 1, is thus to a large extend caused by journal article citations. Since conference papers constitute the largest volume of publications they are *de facto* responsible for less growth in impact than if not incorporated in the analysis. This corresponds to the pattern of the extremely different *citedness ratios* of the two document types 2005-09. A detailed analysis demonstrates that for the 2750 journal articles the citedness is *86.3 %*, whilst the 4384 conference proceeding papers only include *14.8 %* cited at least once!

Table 4. Wind Power document types cited 2005-09 by document types citing 2005-11. Analysis at *document level* and including overlap between types (WoS, 2012).

Cited / *Citing*	**Articles**	**Proceedings**	**Reviews**	**Total**
	2750	4384	189	7323
Articles	9612	2483	1886	13981
Proceedings	3681	1196	433	5310
Reviews	804	193	463	1460
Total	14097	3872	2782	20751

In parallel with Table 3, Table 5 depicts the distribution of top players across the three basic periods plus the recent 2010-11 time slot. In addition, the last row displays the overall citedness ratios per period. For 2005-09 this ratio has diminished in parallel with the inclusion of the vast number of conference proceeding papers.

Table 5. Top-20 countries producing research on Wind Power research 1995-2011. Citedness per period with 7 year windows in last row; not for 2010-11 (WoS, 2012).

	1995-1999			**2000-2004**			**2005-2009**			**2010-2011**	
Countries	**Publ.**	**%**	**Countries**	**Publ.**	**%**	**Countries**	**Publ.**	**%**	**Countries**	**Publ.**	**%**
USA	218	22.3	USA	318	22.0	USA	984	14.0	USA	834	21.1
ENGLAND	216	20.6	***GERMANY***	***123***	***7.9***	PEOPLES R CHINA	943	13.4	PEOPLES R CHINA	480	12.1
DENMARK	***63***	***6.1***	ENGLAND	116	7.9	***GERMANY***	***446***	***6.4***	ENGLAND	220	5.6
SCOTLAND	51	4.8	***DENMARK***	***112***	***6.9***	JAPAN	418	6.0	***DENMARK***	***214***	***5.4***
GREECE	45	4.6	JAPAN	108	6.7	CANADA	381	5.4	***SPAIN***	***212***	***5.4***
GERMANY	***44***	***4.4***	CANADA	91	5.6	ENGLAND	366	5.2	CANADA	204	5.2
ITALY	36	3.5	GREECE	85	5.2	***DENMARK***	***361***	***5.1***	***GERMANY***	***191***	***4.8***
JAPAN	33	3.4	***SPAIN***	***69***	***4.3***	***SPAIN***	***321***	***4.6***	JAPAN	145	3.7
AUSTRALIA	28	2.5	PEOPLES R CHINA	63	3.9	FRANCE	197	2.8	SOUTH KOREA	127	3.2
INDIA	27	2.5	NETHERLANDS	56	3.4	INDIA	197	2.8	ITALY	101	2.6
NETHERLANDS	26	2.4	TURKEY	53	3.2	SCOTLAND	170	2.4	TAIWAN	101	2.6
CANADA	20	2.3	INDIA	52	3.2	NETHERLANDS	165	2.4	AUSTRALIA	92	2.3
SWEDEN	18	1.8	AUSTRALIA	47	2.8	ITALY	150	2.1	INDIA	92	2.3
SAUDI ARABIA	17	1.8	FRANCE	36	2.2	TURKEY	150	2.1	FRANCE	89	2.3
SPAIN	***16***	***1.5***	SWEDEN	36	2.2	GREECE	138	2.0	IRAN	86	2.2
WALES	16	1.4	ITALY	33	2.0	AUSTRALIA	136	1.9	NETHERLANDS	84	2.1
FRANCE	15	1.4	RUSSIA	28	1.7	TAIWAN	123	1.8	TURKEY	81	2.0
PEOPLES R CHINA	14	1.3	SCOTLAND	28	1.7	SWEDEN	122	1.7	POLAND	67	1.7
NEW ZEALAND	13	1.2	EGYPT	25	1.5	IRAN	112	1.6	PORTUGAL	65	1.6
NORWAY	13	1.2	NORWAY	23	1.4	SOUTH KOREA	110	1.6	SCOTLAND	60	1.5
75 Countries			83 Countries			97 countries			95 countries		
Total documents:	1107		Total documents:	1650		Total documents:	7018		Total documents:	3953	
Citedness ratio:		**47.2 %**	**Citedness ratio:**		**61.3 %**	**Citedness ratio:**	**41.7 %**				

We observe Table 5 that the US research effort is stable on aworld share of 21-22 %, recovering from a decrease 2005-09. Germany does not possess that strong top-position in Wind Power research as in the total Renewable Energy research block, Table 3. England, Canada, Japan, Denmark and Spain constitute very strong players, however rather far behind USA and China in recent years. The latter seems to lose some momentum in Wind Power from 2010, as visualized in Figure 2. The Chinese research maximum 2005-09 coincides with the most recent development of installations of new wind power energy capacity taking place immediately after: in 2011 China installed 18,000 MW new wind energy capacity, whilst EU in total only installed 10,000 MW. The same year China´s total wind energy capacity exceeded 62,000 MW against almost 97,000 MW for EU. In comparison USA has installed almost 47,000 MW per 2011 (GWEC, 2012).

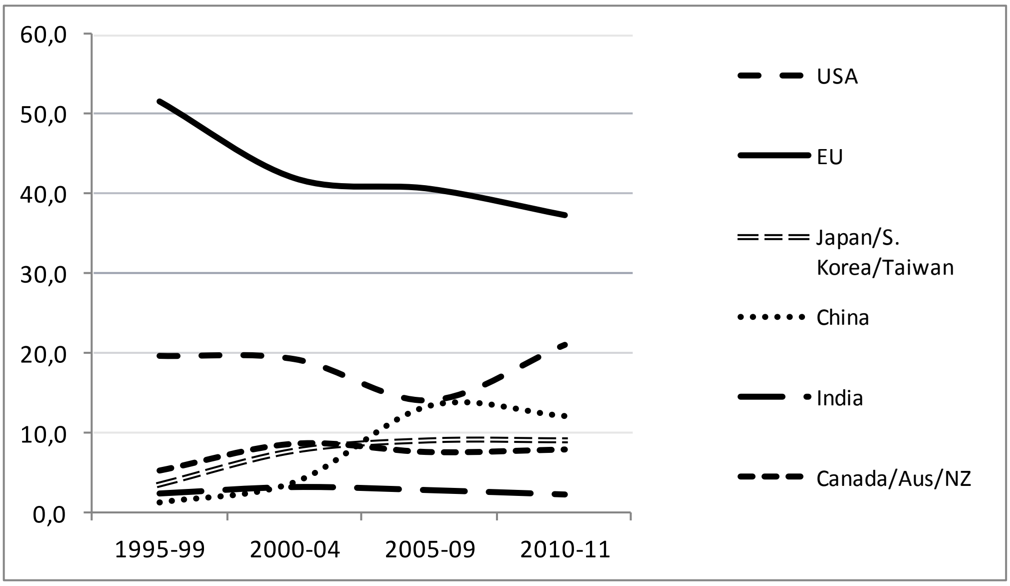


Figure 2. World shares in % of Wind Power research publications 1995-2011 (WoS, 2012).

Figure 2 visualize the trend across the three basic periods plus 2010-11 in Wind Power research. Like for the entire Renewable Energy research block the world share for all other countries not shown on the diagram diminishes over time, from 20.8 % 2000-04, over 15.3 % (2005-09) to 13.6 % in 2010-11. This implies a growing concentration of Wind Power research among the countries shown on the diagram.

One observes an even stronger and constant fall in EU research production in the Wind Power sub-field, compared to Figure 1. While *Spain* alone constantly increase its shares 2000-11 most other EU countries, led by Germany, France, the Netherlands, England and Denmark, *decrease* their world shares during the same period, Table 5.

Considering our assumption about increased intra-EU collaboration during the analysis period then the assumption is *not verified* for Wind Power research. The *collaboration ratios* vary 2000-2011, from *.04* (1995-99) over *.15* (2000-04) and *.08* (2005-09) to *.13* (2010-11), diagram Figure 4. The pattern coincides with that for citedness over the entire period, Table 5.

Citations to Wind Power Research 2005-2009(11)

Table 6 displays the distribution of countries *citing* global as well as EU Wind Power research 2005-2009 during the 7-year citing window 2005-2011. USA displays a larger world share for citing items globally 2005-11 (20.9 %) than for cited publications 2005-2009 (14.0 %), whereas China as second most citing nation remains at the same share (12.2). Germany is ranked lower and Spain as well as Denmark higher as citing nations than for production 2005-09. In general, the 7-year national citing profile 2005-11 mirrors rather well the two-year production profile for 2010-11 alone, the latter covering a substantial portion of citations during the 7-year period.

Table 6. Top-20 countries producing citations globally (left) and to EU (right) in Wind Power research 2005-2009, cited 2005-11. (WoS, 2012).

Citing country	Citing items	%	Country	Citing Items	%
USA	3212	20.9	USA	1681	17.0
PEOPLES R CHINA	1872	12.2	PEOPLES R CHINA	1037	10.5
ENGLAND	1159	7.5	ENGLAND	921	9.3
SPAIN	**984**	**6.4**	**SPAIN**	**805**	**8.1**
CANADA	904	5.9	**GERMANY**	**663**	**6.7**
GERMANY	**856**	**5.6**	CANADA	546	5.5
FRANCE	666	4.3	FRANCE	520	5.3
DENMARK	**556**	**3.6**	**DENMARK**	**503**	**5.1**
ITALY	553	3.6	ITALY	399	4.0
JAPAN	532	3.5	NETHERLANDS	349	3.5
AUSTRALIA	495	3.2	AUSTRALIA	297	3.0
TURKEY	495	3.2	GREECE	278	2.8
INDIA	468	3.0	SCOTLAND	270	2.7
NETHERLANDS	433	2.8	JAPAN	261	2.6
TAIWAN	416	2.7	SWEDEN	250	2.5
SOUTH KOREA	381	2.5	INDIA	240	2.4
IRAN	348	2.3	IRAN	205	2.1
GREECE	341	2.2	TAIWAN	201	2.0
SCOTLAND	325	2.1	SOUTH KOREA	194	2.0
SWEDEN	321	2.1	TURKEY	188	1.9
133 Countries			EU (self-citations)	5091	51.5
Total items/citations:	15.374	30.693	Total items citing EU	9878	100.0

The same pattern concerns the citations *to* EU Wind Power research for the same period, Table 6, right hand side. Half of the USA citations are given to EU. Japan, India, South Korea and Taiwan rank lower as nations citing EU than citing globally. Not surprising seven of the top-10 countries belong to EU leading to an EU self-citation ratio at document level at 51.5 %.

For USA the international citation impact for that period is *6.2* against *1.6* for China! This should be compared to the EU citation impact = *6.4* and the field impact for 2005-09(11), Table 1, which is *4.4.* The *collaboration ratio* for the EU publications citing Wind Power research during this recent period is *.21*; that ratio is a much higher than for the EU publications (.08). For the same period the citing EU publications constitute *41 %* of all the publications citing Wind Power research.

With respect to *knowledge export* Figure 3 demonstrates that the technical engineering research fields are heavy knowledge importers of Wind Power research. Although the environmental sciences play an important role by being assigned as WoS category on a substantial portion of Wind Power publications only two such terms appear as cluster terms in the WoS keyword-based diagram, Figure 3.

Figure 3. Cluster of WoS author keywords (>15) from documents citing Wind Power research 2005-09(11); (WoS, 2012; Ward, 1963).

The cluster diagram also represents an up-to-date *research front distribution* 2005-2011. To the right in the cluster diagram we observe the Renewable Energy research area as neighbour to Energy Policy, biomass and hydrogen power generation. Then towards the left-hand side follow Wind Power generation and the environmental impact issue moving into power conversion, Sustainable Energy types, like Solar Energy, and control mechanisms, wind speed, conservation and distribution. Wind farms, energy storage issues and distributed generation of power paired with forecasting form two significant and related clusters, also associated to wind turbines and power quality.

Wind Power Research 1995-2009: Spain – Germany – Denmark

Table 5 displays the development of world shares and ranking in Wind Power research in the three countries over the three analysis periods plus the additional 2010-11. We observe that Germany is losing ranking *and* world share while Spain alone increases both ranking and share over the 17 years. Since 2000-04 Denmark reduces its world share but maintains its global ranking as number four – yet after a substantial reduction to rank 7 in 2005-09. All three countries increase their productivity in absolute number of publications, Table 5. In other words, during the current economic crisis and whilst EU in general loses world shares in line with Germany and Denmark, Figure 2, *Spain* constantly increase its productivity, world share and ranking in Wind Power research!

Table 7 shows how the productivity and *citedness* develop for the three countries. In particular, the latter ratios follow the general "boomerang-like" trend of the Wind Power field. It is evident that Denmark as well as Spain *do not* suffer from the same low citedness ratio as do Germany and the world 2005-09. Accordingly, one may expect the citation impact of the two countries to be substantial higher than the field and the German impact – see Figure 5.

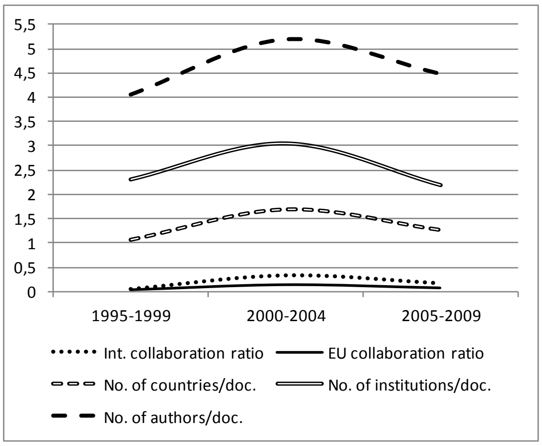
Table 7. Publications and their citedness 1995-2009, Wind Power research (WoS, 2012).

	1995-1999		2000-2004		2005-2009	
	Publications	**Citedness**	**Publications**	**Citedness**	**Publications**	**Citedness**
Germany	44	60.6	123	72.3	446	48.7
Denmark	63	51.1	112	74.1	361	68.4
Spain	16	64.3	69	74.6	321	57.9
Field		47.2		61.3		41.7

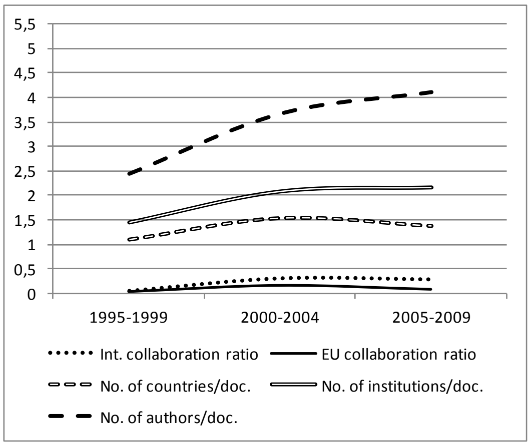
International Collaboration Patterns

Diagram 4a-c demonstrates the international collaboration ratios and number of countries, institutions and authors per publication across the three periods and countries. We observe that the development of citedness for *Germany* not only follows the pattern for the field as such (the "boomerang" form) but is also similar to all the other five publication indicators, displaying a maximum in 2000-04 and a *substantial decrease 2005-09*, Figure 4a. In contrast, *Spain constantly increases* its collaboration ratio and maintains its number of authors, institutions and collaborating countries 1995-09, Figure 4b. *Denmark maintains* its collaboration ratio and number of cooperating institutions, decreases the number of countries it collaborates with 2005-09 and increases its number of authors per document 1995-2009, Figure 4c. For Spain and Denmark these positive developments combined may assure an increase in citation impact, Figure 5, although the number of authors per document is smaller for Denmark and the number of institutions and countries in cooperation are similar for all three countries 2005-09. The quite high international collaboration ratio for Denmark may in addition support a high impact (Moed, 2005).

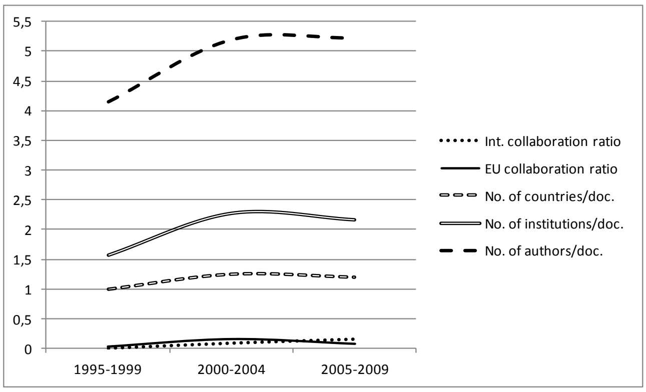
Table 8 demonstrates the countries with which Germany, Denmark and Spain collaborate 2005-09. Each country has its *own profile* of cooperating countries. Spain collaborates with few countries, mainly France, Denmark, UK and the South American region compared to Germany, mainly working with USA, Denmark, the Netherlands and other EU countries. Denmark is mainly cooperating with USA, Germany, China, UK, Sweden and other Nordic countries.



(a) Germany



(b) Denmark



(c) Spain

Figure 4a-c. Properties of collaboration for Germany, Denmark and Spain, Wind Power research 1995-2009 (WoS, 2012).

Table 8. Countries (≥ 2 documents) collaborating with Spain, Denmark and Germany on research on Wind Power 2005-2009. (WoS, 2012)

SPAIN		DENMARK		GERMANY	
no. of countries:	no. of docs:	no. of countries:	no. of docs:	no. of countries:	no. of docs:
21	**321**	**29**	**361**	**33**	**446**
country	**total docs**	**country**	**total docs**	**country**	**total docs**
ESP	321	DNK	361	DEU	446
FRA	11	USA	22	USA	19
DNK	9	DEU	17	DNK	17
GBR	6	CHN	12	NLD	11
PRT	5	GBR	11	GBR	9
ARG	5	SWE	10	FRA	6
MEX	4	ESP	9	CHE	6
ITA	4	ITA	7	SWE	5
CHE	4	NLD	6	AUT	4
USA	2	NOR	6	BRA	3
DEU	2	TWN	4	ITA	3
VEN	2	AUS	3	CHL	3
		GRC	3	CHN	3
		FIN	3	GRC	3
		IRL	3	AUS	2
		CAN	2	FIN	2
		PRT	2	ESP	2
		FRA	2	CAN	2
		CHE	2		

Table 9 illustrates the top institutions producing the more recent Wind Power research in the three countries. The research is disseminated over many institutions in Spain and Germany, but rather concentrated in Denmark to two universities, University of Aalborg and Technical University of Denmark, which also lately has merged with Riso National Laboratories, hence being the top Danish institution. In

Germany and particular in Denmark international wind power producing companies like Vestas, Siemens and Dong are also among the top-publishers in the field. This is not the case in Spain.

Table 9. Top-10 research institutions *producing* Wind Power research 2005-09 (WoS, 2012)

SPAIN		DENMARK		GERMANY	
	no. of docs:		no. of docs:		no. of docs:
	321		361		446
INSTITUTION	**Total docs**	**INSTITUTION**	**Total docs**	**INSTITUTION**	**Total docs**
Univ Carlos III Madrid	38	Univ Aalborg	129	Univ Duisburg Essen	35
Tech Univ Catalonia	34	Tech Univ (DTU) Denmark	106	Leibniz Univ, Hannover	24
Univ Zaragoza	23	Riso Natl Lab, DTU	65	Univ Stuttgart	18
Univ Politecn Madrid	17	Aahus University	12	Univ Kiel	15
Univ Alcala De Henares	13	Dong Energy	9	Ruhr Univ Bochum	15
Univ Basque Country	13	Vestas Wind Syst As	8	Tech Univ Darmstadt	14
Univ Las Palmas Gran Canaria	11	Natl Environm Res Inst	6	Univ Oldenburg	14
Univ Publ Navarra	11	Univ Copenhagen	5	Siemens AG	13
Technol Inst Canary Isl	10	EMD Int. A/S	4	Tech Univ Dredsen	11
Univ Seville	10	Siemens Wind Power A/S	3	Univ Karlsruhe	11

Sources Publishing Wind Power Research in Spain, Denmark and Germany

Table 10 lists the top-5 journals and conferences that publish the Wind Power research from the three countries during the last analysis period.

Table 10. Top-10 lists of sources publishing Wind Power research 2005-09 (WoS, 2012).

SPAIN		DENMARK			GERMANY
no. of docs:		no. of docs:		no. of docs:	
2005-2009	321	2005-2009	361	2005-2009	446
SOURCES	total docs	SOURCES	total docs	SOURCES	total docs
Renewable Energy	26	Wind Energy	61	Wind Energy	29
IEEE Transactions on Energy Conversion	17	Science of Making Torque From Wind	30	Stahlbau	16
Renewable & Sustainable Energy Reviews	14	Energy	9	Energy Policy	12
Epe: 2009 13th European Conference On Power Electronics And Applications, Vols 1-9	12	Journal of Solar Energy Engineering-Transactions of The ASME	9	Science Of Making Torque From Wind	11
Energy Conversion And Management	12	Renewable Energy	9	2007 European Conference on Power Electronics and Applications, Vols 1-10	10

We observe some differences in publication profiles. In the Spanish research production the journals “Renewable Energy”, “IEEE Transactions on Energy Conversion” and “Renewable & Sustainable Energy Reviews” constitute the topvehicles. The journal “Wind Energy” is ranked rather low in Spain. In contrast Denmark and Germany make heavy use of “Wind Energy”. Germany and Spain publish through the same energy conferences.

Citations to Spanish, Danish and German Wind Power Research

The diagram, Figure 5, demonstrates the citation impact development for the three countries in context of the Wind Power field. The German impact follows the usual negative EU pattern for Wind Power research with a peak in 2000-04, cited 2004-06. German impact is presently below the field impact and *far below* the Danish and Spanish impact values.

The international *collaboration ratios* for the documents citing each of the three countries are substantially higher than for the cited publications in each country, Table 4a-c. For the citation window 2005-11 the German ratio is *.60* against the Spanish at *.36* and the Danish ratio at *.42*. The number of countries per citing document is the same as for the cited ones, i.e., around *1.2 – 1.4*.

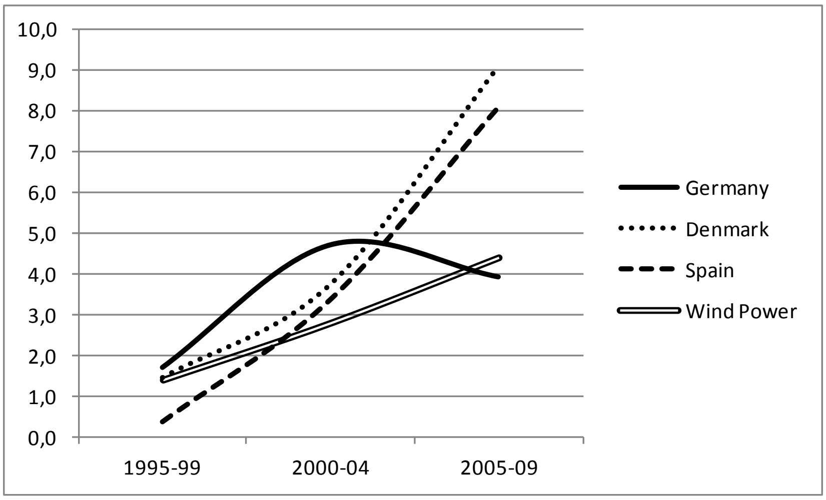


Figure 5. Citation impact Wind Power research 1995-2009, cited 1995-2011 (WoS, 2012).

Knowledge Export of Wind Power Research 2005-11

Table 11 lists the top-quartile countries citing each of the three countries 2005-11. Only 7 EU countries cite Spanish research during this period against 9 for Denmark and 10 for Germany. For Spain the self-citation rate at document level is 19.9 %; for Denmark = 17 %; and for Germany = 21.8 %, with USA as the most citing country. Below, Table 16 demonstrates the correlation coefficients between citing and cited (co-publishing) countries across Spain, Denmark and Germany 2005-09(11); see also Table 8. Figures 6-7 display the correspondence analyses of the countries citing Spain, Denmark and Germany for the two periods 2000-2004, cited 2004-06, and 2005-2009, cited 2005-11. Countries close to the centre of the coordinates, but located in a particular sector, are citing all three countries but mainly the two countries defining the sector. The longer the arrows, the higher the variation for that country. The correspondence map can be regarded as a display of *patterns of knowledge export* of Wind Power research.

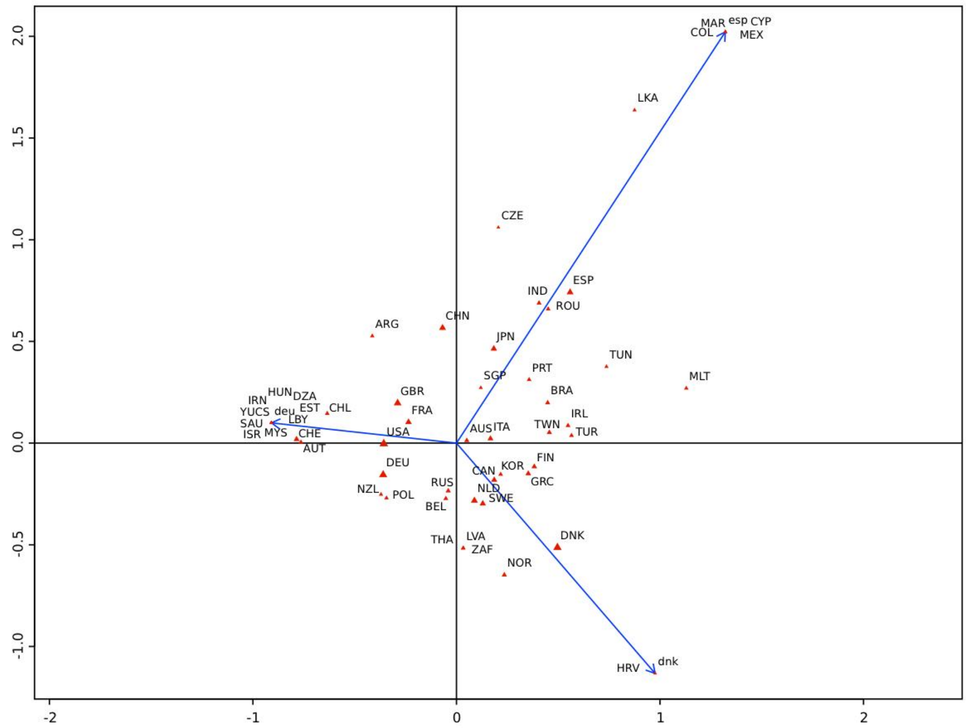


Figure 6. Correspondence analysis of countries citing 2000-06 Spanish, Danish and German publications 2000-2004. Country labels in minuscule. (WoS, 2012).

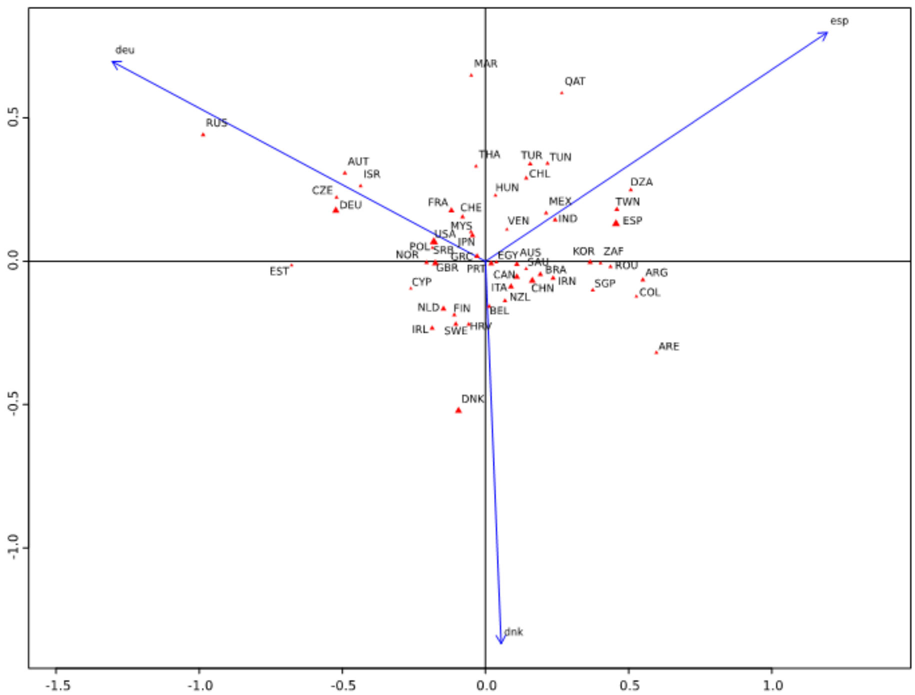


Figure 7. Correspondence analysis of countries citing 2005-11 Spanish, Danish and German publications 2005-2009. Country labels in minuscule. (WoS, 2012).

One observes the tight cluster of central European countries (Hungary, Austria) around the point of the German arrow (NV on diagram) 2000-06. Around the Spanish arrow point (NE) we observe a selection of South American countries. Thus, such countries do not cite the two other countries. In contrast USA is located closer to the centre in the German sector since that country cites all three countries, but mostly Germany. During the following period many countries concentrate around the diagram centre indicating that they cite all three countries simultaneously. However, Russia seems uniquely to cite Germany and a dense cluster is located between Spain and Denmark encompassing China, Canada, New Zealand, Brazil, and Australia, signifying their substantial knowledge import from the two countries, see also Table 11.

Table 11. Upper quartile countries citing Spanish, Danish and German Wind Power research 2005-11. WoS, 2012).

SPAIN		DENMARK		GERMANY	
	no. of docs:		no. of docs:		no. of docs:
	1917		2073		1464
COUNTRY	total docs	COUNTRY	total docs	COUNTRY	total docs
ESP	381	DNK	348	USA	319
USA	260	USA	303	DEU	319
CHN	207	CHN	214	GBR	181
GBR	138	ESP	187	CHN	102
CAN	117	GBR	173	FRA	99
FRA	88	DEU	131	DNK	97
ITA	83	CAN	123	ESP	92
DEU	76	ITA	97	CAN	86
DNK	65	NLD	75	ITA	66
AUS	58	FRA	70	NLD	56
IND	55	AUS	61	JPN	46
TWN	53	PRT	60	PRT	44
PRT	52	JPN	48	AUS	43
BRA	47	BRA	46	GRC	42
IRN	43	SWE	44	RUS	38
JPN	43	IRL	41	CHE	34
TUR	41	IRN	39	AUT	33
GRC	41	KOR	38	SWE	31

Table 12. Distribution of top institutions *citing* Spanish, Danish and German Wind Power research 2005-11. (WoS, 2012)

SPAIN		DENMARK		GERMANY	
	no. of docs:		no. of docs:		no. of docs:
	1917		2073		1464
INSTITUTION	total docs	INSTITUTION	total docs	INSTITUTION	total docs
Tech Univ Catalonia	58	Univ Aalborg	117	Univ Calif Los Angeles	47
Univ Aalborg	31	Tech Univ Denmark	115	Univ Calif Berkeley	38
Tsinghua Univ	31	Tech Univ Catalonia	37	Tech Univ Denmark	37
Tech Univ Denmark	28	Delft Univ Technol	28	Tech Univ Carolo Wilhelmina Braunschweig	21
Univ Beira Interior	26	Tsinghua Univ	25	Univ Washington	21
Csic	24	Queens Univ	23	Chinese Acad Sci	20
Univ Seville	23	Riso Natl Lab	23	Univ Aalborg	19
Univ Alcala De Henares	21	Zhejiang Univ	21	Noaa	19
Univ Tecn Federico Santa Maria	19	Univ Kiel	20	Russian Acad Sci	18
Dakota State Univ	19	Aarhus Univ	19	Univ Calgary	18

Table 12 displays the citing institutions, i.e., the institutions that import knowledge and pay by means of citations (Ingwersen et al., 2000). For *Spain* it is not surprising that Technical University of Catalonia is the most *citing institution*, with Danish and Chinese universities as number 2-4. It is more surprising that University Carlos III Madrid as the most productive institution, Table 9, does not occur among the top-10 of citing institutions. Like in Table 9 the distribution pattern for citing institutions is the same for Spain and Germany, i.e. citations are spread across many institutions, whilst concentrated mainly on the same two Danish universities producing the main portion of research for Denmark.

In addition, the three countries demonstrate very different *knowledge export profiles*. Spain´s knowledge export goes primarily to Spanish, Danish and Chinese institutions. Denmark exports knowledge to many different Chinese and European as well as Danish universities. University of Kiel is the largest German importer of Danish Wind Power research, probably because most German Wind Energy production is located in North-Western Germany. German export goes mainly to many US and a few Danish and German universities.

Table 13. Distribution of *most cited* Wind Power research institutions from Spain, Denmark and Germany, 2005-11. (WoS, 2012).

SPAIN		DENMARK		GERMANY	
Institutions	**Nº of citations**	**Institutions**	**Nº of citations**	**Institutions**	**Nº of citations**
Univ Carlos III Madrid	327	Univ Aalborg	1157	Tech Univ Braunschweig	100
Tech Univ Catalonia	257	Riso Natl Lab	645	Univ Gottingen	73
Univ Las Palmas Gran Canaria	180	Tech Univ Denmark	533	Univ Duisburg Essen	69
Technol Inst Canary Isl	156	Natl Environm Res Inst	154	Potsdam Inst Climate Imp. Res	65
Univ Politecn Madrid	110	Aarhus Univ	109	Univ Karlsruhe	62
Univ Publ Navarra	108	Vestas Wind Syst As	94	Repower Syst Ag	56
Univ Basque Country	100	Energinet Dk	44	Tech Univ Berlin	53
Univ Alcala De Henares	80	Univ Copen-hagen	38	Univ Oldenburg	50
Ciemat	66	Wind Energy Dept	33	Alfred Wegener Inst Pol & Mar	44
Univ Pontificia Comillas	56	Emd Int. A/S	32	Seg Gmbh & Co Kg	41
Total Institutions: 101	2593	Total institutions: 82	3277	Total institutions: 197	1751

Table 13 lists the *highest cited institutions* in the three countries. In comparison to the most publishing institutions, Table 9, and most citing institutions, Table 12, Table 13 demonstrates that the most *knowledge exporting* research institutions from the three countries not necessarily are identical to the highest producing or citing (i.e. knowledge importing) universities. The most cited German research institution is Technical University of Braunschweig, not in top-10 in terms of productivity, with the most productive institution, University of Duisburg Essen Table 9, placed as number 3 on the list. For Denmark there are no surprises, since the usual two central players, including Riso Laboratories now as part of Technical University of Denmark, are also the most cited institutions. A similar situation occurs for Spain. University Carlos III, Madrid, as the most productive institution is also placed as the top most cited institution – with the other central player Technical University of Catalonia as second.

However, one should note that in all three countries commercial Wind Power producers are found among the top-ten most cited R&D institutions. Some of these companies are also found on the top-productivity list, Table 9, e.g. Vestas and EMD. Thus, a knowledge flow exists from both universities *and* commercial companies to academia as well as industry in all three countries.

Table 14 displays the sources citing the Wind Power research 2005-11 produced in the three countries 2005-09. In line with Figure 3 the distribution informs about which subject areas that import knowledge from the countries. The distribution can be compared to the equivalent distribution of sources publishing the cited research, Table 10. For Spain as well as for Denmark we observe that industrial electronics journals are the heaviest citing sources, thus serving as importers of Spanish (and Danish) knowledge. Renewable and sustainable energy as well as energy conversion are also topics making use of Spanish research. Denmark exports in addition knowledge on (wind) energy and energy policy – the latter the biggest hit in German knowledge export aside from geo-physical and space physics.

Table 14. Distribution of sources citing Spanish, Danish and German Wind Power research (Top 10, 2005-2011). (Wos 2012).

SPAIN		DENMARK		GERMANY	
	no. of docs:		no. of docs:		no. of docs:
	1917		2073		1464
SOURCES	total docs	SOURCES	total docs	INSTITUTION	total docs
Ieee Transactions On Industrial Electronics	173	Ieee Transactions On Industrial Electronics	101	Energy Policy	71
Ieee Transactions On Power Electronics	102	Energy	99	Journal Of Geophysical Research-Space Physics	63
Renewable Energy	80	Wind Energy	96	Wind Energy	44
Renewable & Sustainable Energy Reviews	74	Ieee Transactions On Power Electronics	82	Renewable Energy	41
Ieee Transactions On Energy Conversion	63	Energy Policy	78	Renewable & Sustainable Energy Reviews	35
Energy Policy	57	Renewable Energy	73	Ieee Transactions On Industrial Electronics	33
Ieee Transactions On Power Systems	43	Applied Energy	56	Applied Energy	31
Energy	39	Ieee Transactions On Power Systems	41	Energy	24
Electric Power Systems Research	38	Ieee Transactions On Energy Conversion	28	Ieee Transactions On Power Systems	23
Wind Energy	36	Renewable & Sustainable Energy Reviews	28	Ieee Transactions On Energy Conversion	22

For Germany the distribution of citing sources is not strongly correlated to the distribution of producing sources from a qualitative perspective, Table 11; the correlation looks better for Denmark. The Spanish pair of lists seems also to contain some difference in titles.

Table 15. Citing vs cited (Spearman's rank correlation). (2005-2011) (Wos 2012).

	Spain	Denmark	Germany
By countries	0.64 p= 0.0016	0.83 p= 0.00000003	0.75 p= 0.000001
By sources	0.55 p= 0.00000006	0.52 p= 0.000000002	0.31 p= 0.0011

Table 15 sums up the quantitative measures of the correlations. It provides the Spearman rank correlation coefficients for 1) the list pair of countries producing and citing the national Wind Power research; 2) the list pair of sources producing and citing that national research. For country list pairs the critical value is .537. The Danish correlation is thus quite good (*.83*), whilst it is less strong for Germany (*.75*) and somewhat weak for Spain (*.64*). In other words, the same countries with which Spain and Germany cooperate are not citing the countries' research in the same sequential order and proportion. This is more the case for Denmark.

With respect to the list pairs of sources the German correlation between producing and citing sources is very weak (*.31*) and weak for the two other countries (*.52-.55*). The critical value for the Spearman coefficient is .254. All the correlations are significant. The implication is that the profiles of the publication sources producing and citing Wind Power research in the three countries are relatively different from one another.

Discussion

From the analyses above it is evident that although the European Union still constitutes the most productive player, it is losing substantially in world shares in the overall Renewable Energy area as well as in Wind Power research 1995-2011. In particular this decline is serious from 2005 to date. Not only Germany but also other central EU players drop in world shares and ranking compared to, in particular, the rapid developments by China and Taiwan, South Korea and Japan. USA holds its position and stabilizes its world share in both Renewable Energy and Wind Power research. In both research areas Canada, Australia and New Zealand also lose ground, but to a less extend compared to EU. Simultaneously, however, Spain increases its productivity, world shares as well as rankings in both research areas while Denmark stabilizes its position in Renewable Energy as well as in Wind Power research after a decrease 2005-09 in the latter field.

In answering research question 1 one may point to the interesting phenomenon that conference proceeding papers accounts for more than a third of all publications in Renewable Energy, and 60 % in Wind Power research. However, they do not receive citations proportional to their share. In fact, the journal articles in Wind Power research receive more than 5 times as many citations per document compared to conference papers; the latter has a *citedness* as low as 14.8 for 2005-11 and mainly supply citations to journal articles. Nevertheless, the citation impact of Wind Power research nearly triples 1995-2011 as one of the sub-fields of the Renewable Energy block with the highest impact growth, although its impact score compared to the other sub-field impact values is low (*4.4*), 2005-11. Solar Energy research displays a citation impact of *13.9*, Geo-Thermal research shows *7.0* and Wave (Ocean) Energy scores *4.8* in citation impact. The entire Renewable Energy block demonstrates the substantial impact value of *10.7* for that period.

The distribution of citations over countries demonstrates a slightly different pattern compared to the national production of publications in Wind Power research. The US share of citing documents is much higher 2005-11 than its share of published documents, while the German and Danish citation shares are much smaller and the Spanish higher. The EU impact for that period is *6.4* against the US impact of *6.2*, and compared to that of China (*1.6* !) and of the global field (*4.4)*. China is thus highly productive but internationally speaking very insignificant in knowledge export as measured by citation impact in WoS. EU´s self-citation ratio at document level is quite high (*51.5*) and the collaboration ratio for the citing EU documents is *.21*. It is thanks to the collaborative (self-citedness) efforts among the citing EU publications 2005-11, paired with the fact that half of all US citations in Wind Power is given to EU that EU maintains its fairly high impact score. This should be compared to the Spanish and Danish scores that reach 8 and 9, respectively for 2005-11, and the German impact which drop below 4, i.e., beneath the field impact score.

In relation to research questions 2-3 the analyses deal with Spain, Denmark and Germany in particular. Although the productivity for all three countries is constantly growing fast the pattern of citedness is different. In general, citedness peaks 2000-2004 for both field (*61.3* %) and the three countries (*74 %*). However, during 2005-09 the German citedness, and that of the field, drops heavily to 48.7 % and 41.7 %, respectively. The Danish and Spanish citedness ratios also decrease but much less (to 68 % and 58 %). This drop in citedness owes definitively to the influx of non-cited conference papers and results in the heavy decrease of impact for German Wind Power research.

The same "boomerang"-like pattern is observed concerning the German and EU ratios of international cooperation and number of countries, institutions and authors per document across the entire period 1995-2009. In contrast, the equivalent Danish indicators do not drop but rather rise, except for number of collaborating countries, and the Spanish "boomerang" is more flat in shape. With respect to EU and our assumption that collaboration would increase over time due to the politico-rhetoric efforts put forward on energy and climate issues, we observe that intra-EU collaboration in the field actually *decreases* over time.

We also observe that the institutional collaboration profiles for the three countries are different, as are the source profiles as well as the citation profiles of countries citing the three countries´ Wind Power research production. In terms of collaboration some cooperation indeed takes place between the three countries, with consequence for the citation patterns containing some overlap the countries in between. A correlation analysis between citing and producing countries for each of the three countries was done. It showed a rather strong correlation for Denmark, meaning that often the same countries proportionally produce and cite Danish Wind Power research. For Spain and Germany correlations were less pronounced.

The network of citing countries is found through correspondence analyses covering two periods, 2004-06 and 2005-11. One observes a distinct development towards concentration of central players in distinct clusters citing particular countries. For instance, Nordic and NW-European countries are more intensively citing Denmark, while Central EU countries, USA and, in particular, Russia relate to Germany and South American countries and Taiwan primarily cite Spain.

The Chinese Tsinghua University does cite both Spanish and Danish research, aside from local and Danish/Spanish mutual citations. In the German case US universities are the predominant importers of Wind Power knowledge. The Chinese Academy of Science constitutes here the most citing Chinese institution. Among the institutions cited in the three countries´ Wind Power research the most interesting is the fact that the most productive institutions in Spain and Denmark also are the most cited institutions. In German Wind Power research this is not the case. The most cited institution is not among the most productive nor most citing institutions.

It is worth noticing that universities *and* industrial Wind Power production companies are found among the top R&D producing institutions *and* among the top-cited ones.

In order to observe the subject areas that import Wind Power research knowledge we carried out a cluster analysis of the citing document title words. It demonstrates the topical export profile, which merely consists of highly technical concepts covering the range of important aspects and fields associated with Wind Power and Renewable Energy and Energy Policy. Compared to an analysis on the WoS subject areas and categories assigned to the documents through the journal indexing process, we did not observe environmental and ecological concepts frequently applied in the citing titles. By applying the mentioned WoS classification schemes one runs the risk of obtaining classes that not necessarily are representative for the actual contents. In order to check the clustering of the citing title terms we performed an additional cluster analysis of the original publication titles. That analysis demonstrates a similar pattern of technical concepts and terms as for the citing items. The advantage of the analysis based on the citing documents is its currency.

The same significant lack of environmental-ecological topics was also evident when the top-publication sources citing (as well as producing) the national Wind Power research were analyzed qualitatively. In addition, correlation coefficient analyses demonstrated that for Spain and Denmark the correlation between citing and publishing source distributions was weak and very weak for Germany, implying distinct differences.

Conclusions

The contribution had three objectives. First, to analyze the patterns and trends concerning the generation of knowledge on sustainable (or renewable) energy and related research fields through scientific publications. Secondly, to understand to what extent Spain compared to Germany and Denmark contribute to this development. Third, to trace the impact and use of the generated knowledge in further developments and flow through a portfolio of citation-based analyses.

Two assumptions were behind the analyses. First, due to the public policy rhetoric and strategic energy plans, we assumed that EU as region and most individual EU countries have increased their world shares in Wind Power research during the last decade. Secondly, we expected an increase in national and institutional collaboration among EU countries *and* an increasing similarity over time concerning cooperation profiles and citation patterns among the three selected countries. According to the findings all these assumptions and expectations were *not justified*.

The Wind Power research in the European Union decline with respect to world shares, citedness and citation impact. As leading EU country and among the top world producers in Renewable Energy and Wind Power research Germany follows this negative pattern. In contrast the productivity, world share and impact of Spain grow very substantially and constantly during the last decade. The Danish impact score doubles that of the field and of Germany and surpasses the impact of Spain. The most persistent trend over the period is carried out by China and other South East Asian countries by demonstrating a tremendous growth in research volume and world shares – however not in impact and knowledge export.

Further, we had expected a penetration of Wind Power research into other fields in order to explain the almost tripling of citation impact for the field over the 17 year analysis period. This does not seem to be the case according to the findings. Rather, the impact rise owes to an escalation in publication volume and thus a growth in available references turning into citations within the field itself. In addition, the publication structure results in an asymmetric distribution of citations, since the large proportion of conference papers does not contribute an equivalent volume of citations compared to the journal articles, and when providing citations these goes primarily to journal articles.

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Appendix A: Retrieval profiles SAPIENS

Block A: Renewable Energy Generation

Renewable Energy Sub-field:
2 7,104 TS=("renew* energ*" OR "alternative energ*" OR "green energ*" OR "energy polic*") AND PY=(2005-2009)
Refined by: Document Type=(ARTICLE OR PROCEEDINGS PAPER OR REVIEW)
Databases=SCI-EXPANDED, SSCI, CPCI-S, CPCI-SSH Timespan=1995-2011
Lemmatization=On

Wind Power sub-field:
5 7,018 TS=("wind power" OR "wind turbine*" OR "wind energy*" OR "wind farm*" OR "wind generation" OR "wind systems") AND PY=(2005-2009)
Refined by: Document Type=(PROCEEDINGS PAPER OR ARTICLE OR REVIEW) AND [excluding] Web of Science Categories=(ASTRONOMY ASTROPHYSICS)
Databases=SCI-EXPANDED, SSCI, CPCI-S, CPCI-SSH Timespan=1995-2011
Lemmatization=On

Solar Energy sub-field:
8 26,585 TS=("solar energy*" OR "solar radiation" OR "solar cell*" OR "solar photovoltaic*" OR "solar power" OR "solar heat*" OR "solar plant*" OR "solar concentrate*" OR "solar thermal" OR "solar collect*" OR "solar technolog*") AND PY=(2005-2009)
Refined by: Document Type=(ARTICLE OR PROCEEDINGS PAPER OR REVIEW) AND [excluding] Web of Science Categories=(HORTICULTURE OR PLANT SCIENCES OR FORESTRY)
Databases=SCI-EXPANDED, SSCI, CPCI-S, CPCI-SSH Timespan=1995-2011
Lemmatization=On

Geothermal Energy sub-field:
10 2,615 TS=geothermal AND PY=(2005-2009)
Refined by: Document Type=(ARTICLE OR PROCEEDINGS PAPER OR REVIEW)
Databases=SCI-EXPANDED, SSCI, CPCI-S, CPCI-SSH Timespan=1995-2011
Lemmatization=On

Ocean Wave Power Energy sub-field:
14 1,554 TS=("wave power" OR "wave energy*" OR "wave convers*" OR "marine energy" OR "ocean energy") AND PY=(2005-2009)
Refined by: Document Type=(ARTICLE OR PROCEEDINGS PAPER OR REVIEW) AND [excluding] Web of Science Categories=(ASTRONOMY ASTROPHYSICS OR REMOTE SENSING OR PHYSICS APPLIED OR PHYSICS FLUIDS PLASMAS OR NANOSCIENCE NANOTECHNOLOGY OR OPTICS OR CLINICAL NEUROLOGY OR MATERIALS SCIENCE COATINGS FILMS OR TELECOMMUNICATIONS OR ACOUSTICS OR CHEMISTRY PHYSICAL OR PHYSICS CONDENSED MATTER OR RADIOLOGY NUCLEAR MEDICINE MEDICAL IMAGING OR PHYSICS PARTICLES FIELDS) AND [excluding] Web

of Science Categories=(HEMATOLOGY OR IMAGING SCIENCE PHOTOGRAPHIC TECHNOLOGY OR ENGINEERING BIOMEDICAL OR TOXICOLOGY OR BIOLOGY OR BIOPHYSICS OR CRITICAL CARE MEDICINE OR PHYSIOLOGY OR CARDIAC CARDIOVASCULAR SYSTEMS OR FORESTRY OR GASTROENTEROLOGY HEPATOLOGY OR ENGINEERING AEROSPACE OR HORTICULTURE OR MEDICINE GENERAL INTERNAL OR PERIPHERAL VASCULAR DISEASE OR MEDICINE RESEARCH EXPERIMENTAL OR UROLOGY NEPHROLOGY OR PHARMACOLOGY PHARMACY OR ELECTROCHEMISTRY OR PSYCHIATRY OR REHABILITATION OR NEUROSCIENCES OR SPECTROSCOPY)
Databases=SCI-EXPANDED, SSCI, CPCI-S, CPCI-SSH Timespan=1995-2011
Lemmatization=On

Topics to be excluded from "Ocean Wave Power Energy" sub-field:
# 15 414,737 TS=("micro wave*" OR microwave* OR electromagnetic OR laser* OR quantum OR radio) AND PY=(2005-2009)
Databases=SCI-EXPANDED, SSCI, CPCI-S, CPCI-SSH Timespan=1995-2011
Lemmatization=On

Ocean Wave Power Energy sub-field - final:

16 1,444 #14 NOT #15

Renewable Energy Generation Block:

17 41,797 #16 OR #10 OR #8 OR #5 OR #2